Unlocking hidden production capacity in high temperature processing industries

How advanced modeling guided a coal-fired lime kiln
to increase capacity by 20%.

Customer: An emerging global leader
in the supply of lime products
Lime types produced: Quicklime
Kiln type: Long dry lime kiln
Fuel: 100% direct fired coal burner

Most plant operators will appreciate that the burner is the heart of their process. The burner influences kiln output, product quality, NOx emissions, the creation of rings and cycles, and many other process factors

High temperature (energy intensive) processing industries – and the cement industry in particular – focus on fuel savings, enhancing material quality and production rates, and complying with stringent emission regulations.

Until recently, burners were designed from experience, trial and error, and empirical rules. It was only possible to study the combustion reactions in the kiln tube, as current commercial CFD packages cannot predict the material bed temperature, bed temperature profile, or the reactions occurring in the bed.

FCT Combustion's advanced modeling capability combines CFD combustion reactions with numerical bed modeling, resulting in a greater understanding of how the burner design is interacting with the material bed in the kiln. Using these two techniques together provides spatial insight and detailed information about the fluids, flame and product within the kiln. It also provides the flexibility to assess kiln performance under various operating conditions and devise optimal performance settings. Also, unlike most measurement methods, where a single parameter (eg temperature, species concentration) at a single location is recorded, numerical solutions provide 3D mapping of all relevant parameters and material properties in each simulation. By changing burner parameters, and understanding where and when critical material reactions are occurring in the bed, it is possible to unlock hidden production capacity.

Modeling and optimizing a lime kiln

A coal-fired lime kiln, processing calcium carbonate ($CaCO_3$), is the subject of this case study. The calculations were performed using a commercial general-purpose CFD package, coupled with a specialized bed modeling code. A visual onsite observation of the flame showed a long black plume of unburnt coal particles. This indicates an ignition delay, which is one of the challenges addressed in this study. A major challenge in the CFD modeling of rotary kilns stems from the lack of accurate information about the material bed temperature distribution along the kiln. It is a common practice for process and material engineers to estimate the bed temperature profile based on their knowledge and experience of a specific kiln. This approach, however, makes it difficult to generalize or extrapolate temperature profiles for other kilns with different dimensions, burners, materials, production rates etc.

To demonstrate the significance of obtaining a reasonably accurate bed temperature profile on the performance of the kiln, modeling was performed for the existing burner with specific operating conditions using an assumed bed temperature profile, before modeling the kiln using a computed bed temperature profile that was obtained through a two-way CFD-material bed coupling.

The results, shown in Figure 1, clearly show that accurate representation of the material bed temperature has a notable effect on the peak magnitude of the wall heat flux (WHF) profile, its location and on the ignition distance.
To improve the performance of the kiln, the existing burner was redesigned to shorten the ignition-delay distance and enhance the utilisation of the latent capacity in the bed to increase the production rate.

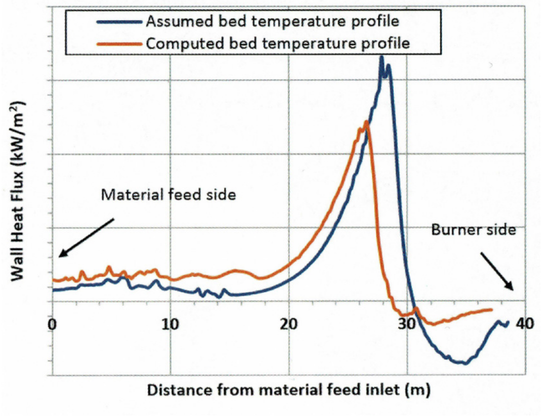

Figure 1. Bed heat flux profile as predicted using an assumed and computed temperature profile of the material bed for the existing burner design.

The positive effects of the modification on the ignition-delay distance and on the wall heat flux profile are shown in Figure 2. It reduced the ignition-delay distance by approximately 5m, which consequently reduced the heat transfer from the inner refractory and the material bed to the secondary air, without affecting the shape of the WHF profile.

The flow pattern in the kiln indicated the formation of two large vortices (on the opposite sides of the kiln) immediately downstream of the nose-ring.

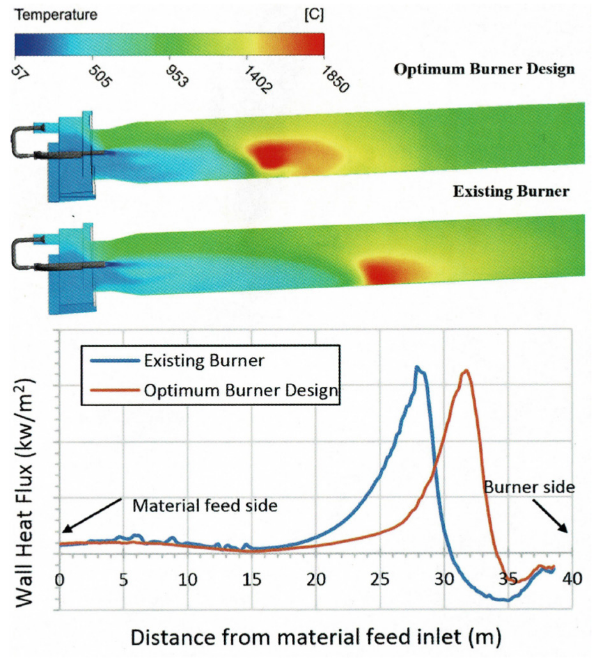

Figure 2. (a - top) Temperature contour map showing the earlier ignition in the optimum burner design as compared to the existing burner. (b - bottom) Wall heat flux profile of the flame produced by the optimum burner design and that with the existing burner.

This flow recirculation is effectively transferring heat from the flame region to the incoming air streams, and hence preheating the incoming secondary and conveying air streams.

Preheating the air to raise the bed temperature and production levels

The preheating effect showed the incoming secondary air temperature at 300°C, rising to approximately 570°C within less than 1m. Typically, preheating the air reduces ignition delay distance and enhances flame stability. In this kiln, however, the high velocity injection coal particles and the low secondary temperature counter the benefits of the preheating and cause a delay in ignition distance to about 3.6m from the burner.

The flame temperature, however, reaches its peak value further downstream, approximately 6.5m from the tip of the burner. The flame is touching the material bed, which is mainly due to the burner pipe being oriented towards the material bed. The predicted delay in ignition is consistent with the site observation.

The predicted gas, refractory and bed mean temperature profiles indicated that the inner refractory and the material bed temperatures reach thermal equilibrium approximately 15m downstream of the burner's tip.

They remain in equilibrium all the way to the back end of the kiln. A positive WHF value indicates the transfer of heat from the gas/flame to the walls (ie the inner refractory and the material bed). However, a negative value indicates the heat is being transferred from the walls to the gas. This occurs when the temperature of the refractory or the material bed is higher than the gas temperature. In this kiln, a negative WHF region extends from the nose-ring to approximately 5m from the tip of the burner, as shown in Figure 2.

It is worth noting however that although combustion commences about 3.6m from the burner, high rates of heat-release occur approximately 5m - 6m from the burner.

It is interesting to note that the bed temperature rose sharply by 300°C approximately 5.5m away from the tip of the burner. This sharp temperature rise is an indication of the completion of the endothermic calcination process in the bed. That is, the heat transfer from the gas is being converted into sensible energy in the material bed, rather than being used for material calcination. The bed temperature then starts to decrease closer to the burner, as this sensible heat is transferred back from the bed to the secondary air.

The prediction of the material bed modeling for the existing burner showed that calcination is completed approximately 6m before the material reaches the cooler chute (Figure 3-a). This sharp rise in bed temperature, however, offers an opportunity to increase the production rate by utilisiing the embedded sensible bed energy. Accordingly, the feed rate is increased to 120% and later to 130%, as shown in Figure 3-b and Figure 3-c respectively.

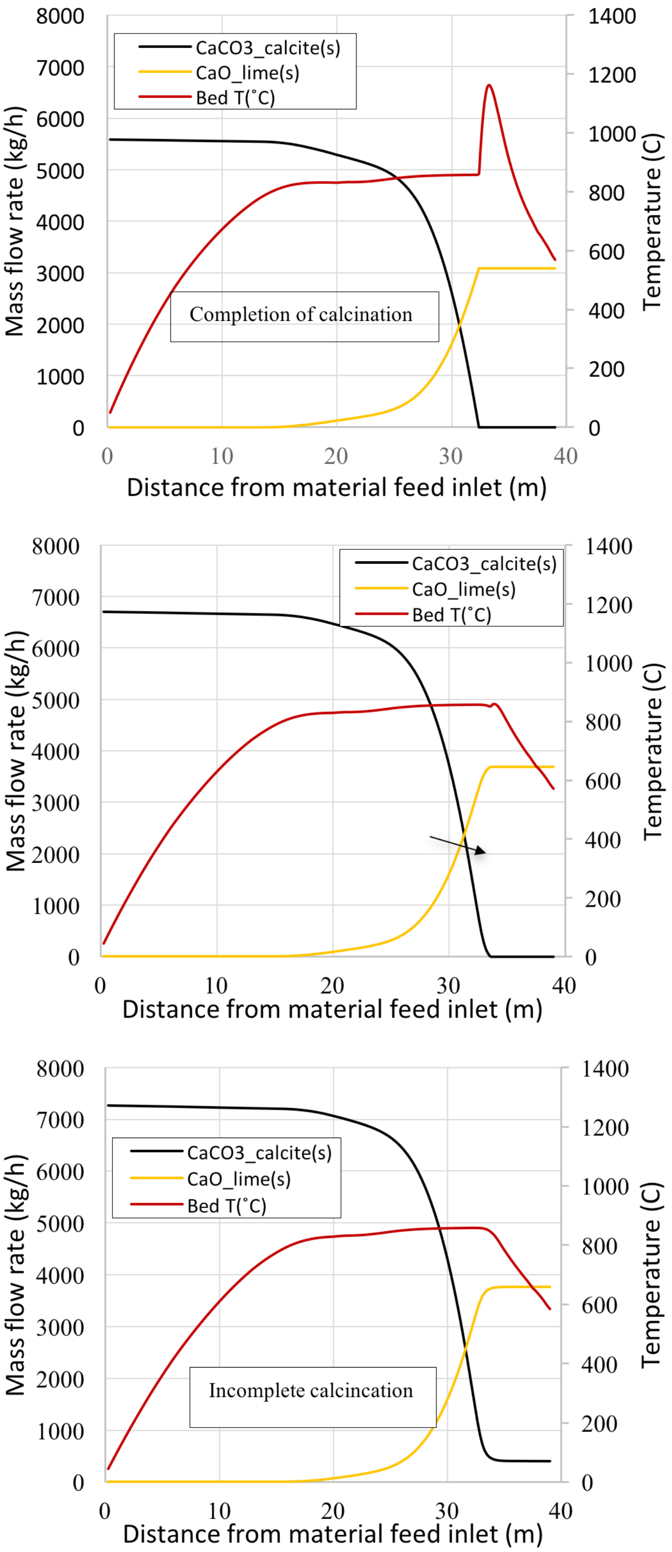

Figure 3. Material bed calcination profiles for: (a - top) 100%, (b - middle) 120%, and (c -bottom) 130% of the original feed rate. The red line is bed temperature, the black and yellow lines are % of CaCO3 and CaO.

A complete calcination is achieved when the feed rate increased to 120% of its existing feed rate (Figure 3-b). This implies that the current firing capacity (using the redesigned burner) is sufficient to handle the additional feed. The figure also shows that the embedded sensible heat in the bed is no longer wasted, which indicated improved process heat utilization. The production of CaO is increased by 20%. The efficiency of the actual-to-theoretical $CaCO_3$/CaO conversion is also increased from 81% to 90%. Further increase in the feed rate to 130% of the existing rate, however, (without increasing the firing rate) has resulted in an incomplete calcination of 5.5% of the feed material (Figure 3-c).

Overview of project benefits

Combining advanced CFD modeling capabilities with a bed modeling code provides new knowledge that can be used to analyze and optimize burners, kilns and materials processing plants.

These capabilities are used regularly at FCT Combustion for problem-solving, burner design and optimization in high-temperature processes such as lime, cement, pulp & paper, alumina, nickel and iron pellet.

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